5. Drexel: Voltmeter showed in excess 50,000 volts for altitude 1,600 meters. Steady stream of brilliant sparks jumping 10 centimeters. Thunder first heard at 8.33 a. m. At 9.23 flash of lightning and thunder; 4,000 meters of wire out. Effect on wire as follows:

Length from head kite (meters)	Diameter of wire (millimeters)	Condition
0 to 800	0.9	Destroyed.
800 to 1,600	1.0	Brittle like glass.
1,600 to 1,900	1.0	Dark blue.
1,900 to 2,075	1.0	Yellowish brown and dark blue.
2,075 to 2,260	1.0	Very dark blue.
2,260 to 3,600	1.0	Apparently not affected.
3,600 to 3,680	1.1	Light brown.
3,680 to 3,800	1.1	Dark brown.
3,800 to 4,000	1.1	Dark brown to dark blue.

The string attaching head kite to wire was burned. That portion of the wire within the lower stratus cloud (below 1,000 meters) showed no ill effects from lightning, whereas that portion between base of cloud and earth (650 meters) was considerably affected in spite of the fact that it was wire of larger diameter, and therefore less resistance. The wire in the dry air (2,300 to 1,300 meters) between the two clouds layers was either entirely destroyed or rendered unfit for use. It is evident that the electric charge originated in the upper cloud layer and much of it passed along the wire into the lower cloud. A portion continued to earth but did not affect the wire because of the moisture on it, but did injure the wire in the drier air below. Thus an airplane might form part of the path of discharge. (See Supplement No. 10, M. W. R., 1918, pp. 5–6.)

6. Broken Arrow: 1,800 meters out; three kites. Stratus cloud 400 meters high. Lightning strikes head kite and completely destroys wire from kite to reel house leaving along the path a discharge a streak of thick yellowish brown smoke. If this discharge occurred in 0.001 second, the voltage is not far from 3,000,000, or about that of the artificial near lightning of Peek. Compare this with the next case.

7. Drexel: 3,535 meters of wire, except 20 or 30 near the reel, vaporized. The lower portion fused.

8. While not a kite wire record, it may be mentioned that on April 16, 1926, an airplane carrying eight passengers going from Paris to London was struck near Beauvais. A large patch of fabric was torn out. the compass demagnetized, one of the main spars scorched, all bondings fused, and one aileron badly damaged.

Doctor Dorsey has advanced the theory that there are electronic darts, or localized stream lines of electrons and that a positive stroke advances by a series of steps depending upon the occurrence of free electrons. Branching is to be expected; while in a negative stroke the electrons advance in a mighty rush. He objects to Doctor Simpson's deductions from the preponderance of negative polarity in side-split branches, as shown in many photographs. Inspection of the 3,600,000 volt flash herewith shows, curiously enough, split-off discharges in both directions from the same flash.

Humphreys has calculated (Physics of the Air, p. 396) in the case of a hollow tubular conductor crushed by lightning and assuming certain temperatures, an amperage ranging from 19,470 to a maximum of 100,000. With the latter value and assuming a megadyne pressure on the inner tube, there results a pressure of 2,638 by 10^4 dynes per square centimeter or roughly 26 atmospheres. He warns, however, that these are rough estimates and "that this particular discharge presumably was exceptionally heavy since it produced an exceptional effect." He also quotes Pockels estimate of 10,000 amperes. Mr. S. A. Korff, of the General Electric Co., has called my attention to Steinmetz's estimate of the energy as 10^1 watt-seconds or 2.8 kilowatt-hours which is only a thousandth of Wilson's value. Larmor has estimated the energy as 28 kilowatt hours. (Proc. Roy. Soc. 1924, Vol. 90, p. 312.) Since the voltage breakdown of air is 9 by 10^9 volts it seems likely that estimates exceeding this are too high; and as the breakdown is probably progressive, values of 1.2 by 10^7 volts are ample, thus bringing the energy value to approximately 28 kilowatt-hours.

For the benefit of the lay reader then we may say that in our opinion the energy of an average flash of lightning does not run much over 10 kilowatt-hours or, let us say, enough to operate three ordinary toasters (300 watts) for 10 hours.

PHENOMENA PRECEDING LIGHTNING

By Alexander McAdie

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In the Meteorological Magazine June, 1928, p. 113, Mr. R. S. Breton, writing from Tung Sung, Southern Siam, states that on a number of occasions he has noticed a sharp "vit" or "click" accompanying lightning that has struck something in the immediate neighborhood, preceding the thunder by a perceptible fraction of a second.

He adds that he has three times noticed that animals show alarm immediately before a flash and that in one case a dog walking on grass turned and began to bark angrily in the direction of a very strong flash that came one-fourth second after, striking several of a group of trees 200 yards away. He mentions two occasions when fowls rushed for shelter from the open in alarm before a very near discharge actually took place. In each case the discharge was a very powerful one, taking place on dry soil before rain had fallen. He asks "if it may be that the sensitive feet of the dog could detect vibrations before the discharge took place."

The editors of the magazine answer "that the 'vit' or 'click' accompanying lightning which has struck close by appears to be new; no reference to any similar observation can be found in the literature and at present it is not possible to offer any explanation."

Clicks preceding intense lightning flashes are common at Blue Hill Observatory and undoubtedly can be heard elsewhere under certain conditions, when an insulated metallic conductor is exposed, in a strong electric field, and a grounded conductor is close by. At Blue Hill every intense flash within a radius of 1,000 meters gives this click preceding thunder by an interval which is a function of the distance of the flash. Thus for an interval of 0.4 second (a frequent value), with mean temperature of air column from ground to cloud 1,100 kilograds (303° A. or 86° F.) relative humidity 90 per cent absolute humidity 27 grams per cubic meter of space, wind direction 235° (SW. by S.) velocity 7 meters per second, the distance is

$$d = t\ (V_0\sqrt{T/1000}) + \text{wind}$$
$$= 0.4\ (332.11 \times 1.05) \times 7$$
$$= 142\ \text{meters}$$

Intervals as large as six seconds indicating a flash distant 2 kilometers or more have been noted.

Regarding the behavior of the dog, it would seem to be not so much a question of sensitive feet as a matter of insulation and increasing electrification to a degree that the hairs, for instance, become discharging points. This bristling can be seen readily on animals caught in thunderstorms near the top of a mountain. I recall being near the summit of Mount Whitney (4,420 meters above sea level, 14,502 feet), during a thunderstorm. The hairs of the burros (pack animals) stood out straight,

and a faint hissing could be heard. A metal button on my cap gave a tingling sensation. I kept wondering how long it would be before a flash of lightning would demolish the entire party of astronomers as they proceeded in close formation to the summit. I think we had a narrow escape from disaster. During a week's stay at the summit we had several thunderstorms, when the lightning seemed to be below us.

The feeling of uneasiness preceding lightning flashes may be due, aside from effects of pressure, temperature, and humidity, to the increasing electrical strain, as a charged cloud comes over the position of the observer. We know from our quadrant-electrometer measurements that at such times the potential gradient increases steadily from 50 volts per meter to 10,000 or more. A jet of water from an insulated collector exhibits many interesting changes as the charged cloud approaches. In fact we can tell just about when the flash will occur. We can also detect and record discharges which an observer fails to detect, if dependent on the eye alone. With each flash there is an instantaneous equalization of potential and return of the needle to zero.

Prof. C. T. R. Wilson has shown (Phil. Trans. A Vol. 221, p. 112, 1921) that continuous currents carried by ions moving in the strong field below the cloud, exist, these ions being produced as a result of point discharges from trees and bushes below the cloud. Prof. B. F. J. Schonland has estimated the magnitude of these currents. (Proc. Roy. Soc. A. Vol. 118, p. 252.)

Using an insulated Acacia Karroo tree, a small thorn tree, about 12 feet high with plenty of thorns, he measured the field and current strength. With a field of negative 16,000 v/m, the current as measured by a unipivot galvanometer with one terminal to tree and other to earth, was 4 microamperes. His table shows that during 230 minutes of strong negative field, the tree discharged 0.0129 coulomb of positive electricity upward, while during 10 minutes of strong positive fields it discharged 0.0001 coulomb of negative electricity. The latter effect was due to a mammatiform cloud residue, the actual storm having receded far away. Confirming previous measurements in 1926, some made in 1927 lead him to estimate the quantity of electricity in an average vertical flash, whether to ground or in the cloud, of 3 kilometers, as 15 coulombs.

We may quote from an earlier paper by the same author, in which the polarity of distant, intermediate, and near-thunder clouds is discussed. We give only intermediate and near storms, although the distances are much greater than where the "click" occurs with the flash. But even at these larger distances it is plain that the increase in the strength of the field is of a progressive character; and hence in case of very near lightning, there might easily be experienced by insulated animals excitation of the fur or hair. Or again the dog may have simply heard the hissing caused by point discharges from the leaves of the tree, which under the conditions given would be excessive. The following particulars have been excerpted from "The polarity of thunderstorms," by B. F. J. Schonland, Proc. Roy. Soc. A Vol. 118, 1928:

Intermediate storms.—Figure 6: Storm 25, 24/1/27, 15 h. 7 m. to 15 h. 12.8 m., about 1½ hours after Figure 1.

This is a portion of a record taken on the ball, which had to be lowered to a height of 1 meter above the ground, owing to the negative field of −4,000 v/m prevailing. The following outside observations were made: 7½ m. flash in cloud . . . 8.0 m. double

flash to ground at 10.4 kms. . . . 8½ m. flash in cloud . . . storm getting nearer . . . 9¾ m. flash to ground at 5 kms. . . . 10¼ m. flash in cloud . . . 12 m. flash in cloud at 5 kms. . . . The storm now came overhead and gave a strong negative field of −5,000 to −10,000 v/m, accompanied by heavy rain, which conveyed a positive charge to the test plate. The record shows 22 positive and 16 negative field changes.

Figure 7: Storm 41, 16/2/27, 16 h. 18 m. to 16 h. 23 m. This record was taken on the ball at the usual height. The storm moved over the station at about 30 kms. per hour. When distant it gave 7 negative and 3 positive field changes. During this record it approached from 11.3 kms. (flash at 18.8 m.) to less than 7 kms. (at 20.8 m.) and at 26¼ m. a flash to ground took place at a distance of 2.8 kms. The field, which was −530 v/m at 21.8 m., increased to −6,000 v/m as the storm came overhead. The field changes at 20.8 m. and 21.4 m. were double, +680 and +1,080 followed by −360 and −760 v/m, respectively, at intervals of about 0.5 second. The record shows 7 positive and 3 negative field changes.

Figure 8: Storm 30, 31/1/27. This record was taken on the ball during the approach of the storm and shows 18 negative and 7 positive sudden field changes. Flashes to ground occurred at 18.4 and 20.4 m., which the record shows to have produced positive changes of field.

The ball was lowered to measure the field at 17.3, 19.6, and 21.4 m. Initially, −109 v/m, the field rose to −420 v/m as the storm approached and later became so strong as to drive the meniscus out of the field of view. At 32 m., after the close of the record, it had reached −10,000 v/m, and the next record, which is shown in Figure 9, was obtained.

A record was made at 17 h. 10 m., when the storm was at a distance of 11 kms., showed that the steady field was then +40 v/m.

Near storms.—Figure 9: Storm 30. Test plate, 17 h. 34 m. to 17 h. 44½ m. The distances of 9 of the flashes have been determined from the thunder marks following the field changes and lie between 3 and 6.4 kms. The test plate was uncovered at 34¾ m. and covered for a few seconds at 37, 37¾, 40, and 42½ m., the field varying from −8,800 to −10,600 v/m. The largest sudden change of field, at 35.5 m., amounted to +14,800 v/m and was due to a flash in the cloud at a distance of 4.4 kms. It was followed 3 seconds later by a change of −3,000, v/m. The other negative change, −2,000 v/m, occurred at 39.6 m.

Rain started to fall at 35.5 m., was noted as heavy at 40 m. and as very heavy from 41½ m. to the end of the record. This is the cause of the upward slope of the record, which indicates an average current of 6.5×10⁻¹⁴ amps./sq. cm. from 34¾ m. to 42½ m. The peculiar hump at 43½ m. is probably due to the heavy rainfall. Flashes to ground occurred at 37.5 m. (5.4 kms.) and 38.8 m. (3.0 kms.). The record shows 34 positive and 2 negative field changes.

Figure 10. Storm 36, 9/2/27. Test plate, 14 h. 6.5 m. to 14 h. 22 m. The distances of 12 of the flashes have been determined and lay between 2 and 7. 2 kms. The test plate was covered for a few seconds at 7, 10, 11.7, 13.6, 15.2 and 19 m., the field varying from −11,800 v/m to −3,500 v/m. The largest sudden change of field amounted to +11,800 v/m and occurred at 9.4 m., momentarily reducing the field to zero.

Three small negative changes of field occurred at 8.7, 11.3, and 1.22 m., the first two being due to discharges at distances of 5.4 and 11.2 kms., respectively. Two larger negative changes occurred at 16.6 m. at the end of a half-minute interval during which a positive field of the order of 6,000 v/m prevailed. They reduced the field by 14,000 v/m in two jumps of −4,700 and −9,300 v/m about 1½ seconds apart.

Rain fell at 12 m., becoming heavy at 13 m., and the upward slope of the record indicates that this was positively charged and have an average current of 4.9×10⁻¹⁴ amps./sq. cm. between 11.7 and 15.2 m.

The full history of this storm is as follows: At 12 h. 20 m. it was approaching from a distance of 40 kms, and gave 90 negative and 4 positive field-changes. At 13 h. 12 m. it was 6 kms. away and gave rise to a field of −7,000 v/m which rose to −16,000 v/m at 13 h. 41 m. and continued to vary from −8,000 to −12,000 v/m (except for the half-minute of positive field referred to) until 14 h. 27 m. During this half-hour the discharges were between 2.0 and 7.2 kms. off and 72 positive and 5 negative changes were observed. Another record was taken at 14 h. 27 m., just after fig. 10, when the active center was reported to be moving away and the flashes were at distances lying between 7 and 10 kms. This record shows 9 positive field changes followed by 8 negative ones and the sign of the field-changes evidently reversed. The steady field, however, remained between −5,500 and −8,100 v/m for another 31 minutes.